SURFACE BROACHING.

Paper presented to the Institution, London and Eastern Counties Sections, by H. E. Weatherley, M.I.P.E.

BY way of preface it should be said that the compiling of this paper was done from the point of view that surface broaching is a relatively new subject, consequently some of the matter it contains might appear elementary in character, but on such a basis cannot be omitted. From a production point of view, surface broaching or, to give it a more appropriate name, external broaching, can be applied to so many of the machining operations at present done by other methods that it is only natural it should have the attention of all those interested in cost reduction, offering as it does the advantages of higher rate of production, greater accuracy, better finish, and longer set-ups. Any one of these advantages, taking into consideration the particular difficulties which this type of machining is to overcome, can be of sufficient importance to justify by itself the adoption of surface broaching.

While at present most of the external broaching is being done in the motor and allied industries, the experience gained therein has led to developments of machines and methods, and simplification of tool design, all of which progress and widen the scope every time a new proposition is handled, so that it is easy to believe that it will, in a relatively short time, enter all branches of the engineering industry.

Surface broaching, as we will refer to it, is very much akin to internal broaching, inasmuch as both methods employ a tool with a multiplicity of cutting teeth removing the metal in one straight pass progressively, but it differs from internal broaching in that some provision in the nature of guides or supports is necessary to enable the broach to reproduce itself. It has been generally supposed hitherto that large quantities were essential but actually, even where quantities are relatively small (and by relatively small I mean a batch of 100), if a selection of components can be made to suit the set-up, there are many occasions when surface broaching can be the most advantageous method.

Consider for a moment the number of components which come up before you for review as to the best manner of machining, and you may recall pieces with slots, flat faces, two or more faces that

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have to be machined accurately in relation one to another, forms, contours, etc. For instance, your problem might be the machining of a form or contour, such as is represented by a portion of a steering arm seen on Fig. 1.

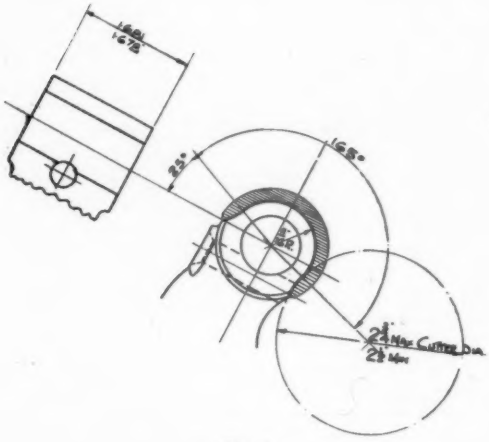

Fig. 1.

The shaded part represents the amount of stock which has to be removed, namely, $^{5}/_{16}$ in., and also outlines the form to be machine. This form is made up of three radii and, as these have to be blended together, it is desirable to machine all of them in one operation.

This is only possible, economically at any rate, either by means of profiling, or by the method now employed, that is, broaching, the results of which are very much in its favour, the comparative figures being three per hour by the profiling method, and 100 per hour by broaching, doing two at one time.

Then again you may have amongst them a plunger pin (Fig. 2.) having three slots in different planes. The nature of broaching being a straight line movement, this method of machining enables faces or slots in different positions in the same plane to be broached simultaneously, thus securing alignment and position. It also ensures accurate machining as, during the period when the finishing section of the broach is in operation, the load is reduced so much that it becomes purely a shaving and sizing operation, enabling very close limits to be maintained and, using a two-spindle machine, a very high rate of production, in this case 600 per hour.

These two examples, which are in the nature of extremes, illustrate the ease and simplicity with which such parts can be produced and, while it is true that surface broaching has in the past been considered only in relation to the very special job, or jobs, it was difficult to do by any other means, it is in the more universal applications that its future really lies, when one may reasonably expect

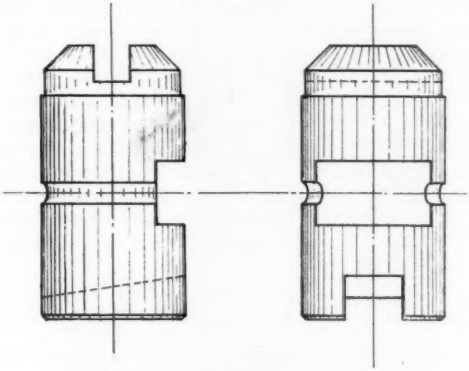

Fig. 2.

to see a line of broaching machines, as one sees other production machines. In fact, when one sees a piece being broached, the advantages are so marked that one wonders why this method of machining did not have the attention of the designer years ago, even though there were not then available developments such as we have to-day. However, before the full benefits of this form of machining can be obtained, it is necessary that much more care and attention be devoted to the purchase of forgings and castings. To enable the importance of this point to be appreciated, a component has been selected which demonstrates the need for reducing stock removal to reasonable proportions (Fig. 3).

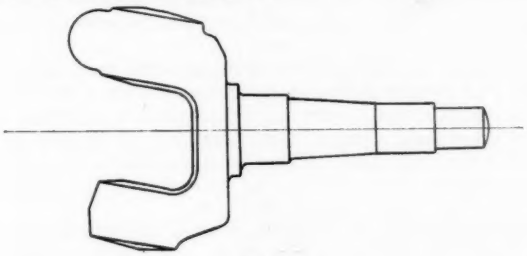

Fig. 3.

The component in question is a stub axle, a piece which will be familiar to you all, and which, owing to the nature of its design and shape, and the methods employed in producing the forging, usually has a big hump left on the faces and a large amount on the radius in the corners which, in addition to the flash left all round, makes a comparatively large depth of material to be removed.

While the actual area is relatively small, it does have a very serious effect upon the rate of production as, since there is a limit to the amount of stock that can be removed per tooth, it can have the effect of at least doubling the length of broach. This might then be beyond the stroke capacity of the machine, and necessitate two broaches, and while it can many times be demonstrated that a piece requiring two broaching operation for stock removal can still be an economic proposition, it is obvious how enormously production can be improved when the component can be completed in one pass of the broach. This may be more readily appreciated from the table shown in Fig. 4, giving theoretical number of strokes per hour, including cutting and return.

THEORETICAL NUMBER OF DRAWS PER HOUR OBTAINABLE

(Including two seconds per draw to start and stop).

	Cutting speed per minute			
Draw :	15 ft.	20 ft.	25 ft.	30 ft.
12 in.	600	720	820	900
18 in.	450	550	640	720
24 in.	360	450	530	600
30 in.	300	380	450	515
36 in.	255	325	390	450

Fig. 4.

Taking the mean figures of this table, 2 ft. length of stroke, and a cutting speed of, say 20 ft. a minute, this shows that, instead of 450 pieces an hour, the production with two passes would be *less* than half, as a double loading and unloading time would have to be allowed for.

It is difficult to believe that forgings and castings cannot be produced to a greater degree of accuracy. Surely it is only a question of closer attention to dies and patterns, and the use of a higher grade of equipment, which more determined resistance to the suppliers of forgings and castings would achieve, and this point is most seriously commended to the attention of the management, as after all it is a management problem.

The following examples, all of which have been running for periods ranging from six months to two years, show what results can be

obtained when the component is presented to the machine with a reasonable amount of stock to be removed, and serve further to demonstrate the advantages that surface broaching can afford. (Fig. 5).

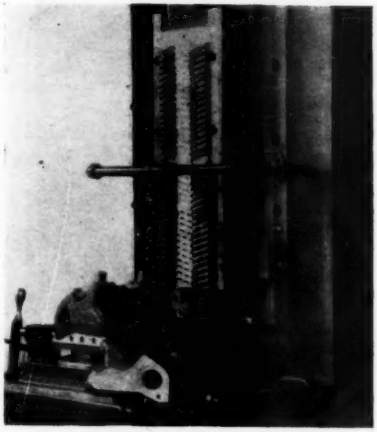

Fig. 5.

The first illustrates the machining of the flat face of a cast iron water pump body. A set of high speed steel broaches, 24 in. in length, provided for a maximum stock removal of $^{3}/_{16}$ in., at a cutting speed of 30 ft. a minute. The production averaged 100 pieces per hour, which included a setting time of fifteen seconds each, this time being required partly owing to the component being of rather a fragile nature, but mainly owing to casting irregularities—another illustration of the point already stressed. The average life of the broach was 6,000 to 8,000 pieces between re-grinds. This set up also shows how a variety of components in similar material, with a flat face of an area within the width of the cutting face, can be covered by simply changing the work holding fixture.

The next example deals with a series of broaching operations on a connecting rod of a popular make of car (Fig. 6).

The set up for the first operation shows the tools arranged to broach the faces of the big and small ends at one pass, so that at each stoke of the machine one connecting rod is finished on all four

Fig. 6.

faces. This illustration also shows how the component is located and clamped. The floor to floor time is twenty-five seconds each.

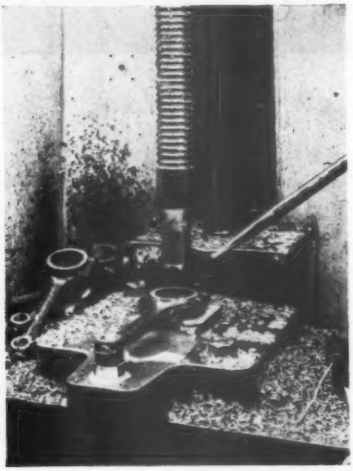

Fig. 7.

The second operation (Fig. 7). is broaching an oval hole from a round drilled hole, removing approximately $^{5}/_{32}$ in. The two points of particular interest in this example are, first, that the

broach is held rigidly and parallel in relation to the fixture location point, throughout the whole length of its broaching stroke ; and, second, that no clamping is necessary, the fixture being provided merely with location points. The floor to floor time on this is thirty seconds.

Fig. 8.

The next operation is a most interesting one (Fig. 8). It shows a set-up arranged to machine on the left-hand side the four faces of the bolt bosses and to split the cap half-way through, and on the right-hand side to complete the splitting operation, so that at each stroke of the machine four faces are finished, and the cap separated, the production floor to floor being forty-two seconds. After a few weeks' experience on these three operations, it was found that the severest of them called for the broaches to be re-ground at the end of a week's run, during which time they produced 2,500 pieces. It was therefore decided that two more sets of broach inserts should be made, with a view to having one set on the machine, one set in the tool stores, and one set for re-grinding : so the matter has now become a regular routine of weekly changing of tools, and fulfilling requirements on this size of rod and cap.

The last shows the final broaching operation (Fig. 9) which is shaving and sizing the faces of the two halves for final assembly, which operation only occupies eleven seconds. As the stock re-

moved in this case is only a few thousandths, the call on the broach is very light ; consequently, it is only necessary to change the tools every three or four weeks.

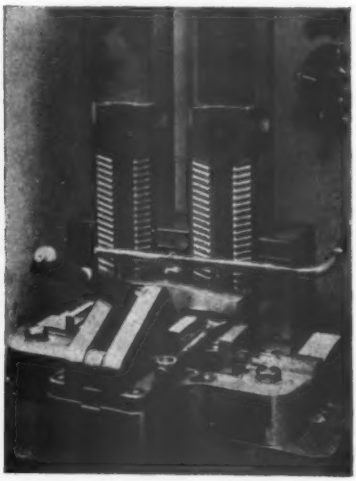

Fig. 9.

The examples just shown demonstrate the very valuable feature of the possibility of planning on a basis of an average set-up for a week. In fact, with a machine properly tooled up, even running at full capacity, a weekly changing of tools can be the rule and not the exception.

It is not the intention to deal at length in this paper with the question of broaching machines themselves, but it is of course necessary in studying a proposition to establish the type and capacity of machine it is intended to use, and, in view of the very wide range that is available, the designer is not restricted in this respect.

Machines used for surface broaching can be divided into two classes—those which are designed exclusively for surface broaching and those which can be used for both internal and external broaching. The machine which is arranged exclusively for surface broaching has the distinctive features of incorporating in its design provision for guiding the sliding member to which the broach bar is fixed, and facilities to assist unloading, by a shuttling table provided with adjustable stops to allow for adjustment between broach and work piece ; and of being more economical in tool and fixture cost. In

the case of the dual purpose machine, provision to take care of the above factors has to be incorporated in the fixture.

Other points which call for mention are that the machine should be hydraulically operated, and that it should have adequate provision incorporated in its construction to take care of such emergencies as jamming during its cutting stroke. In making only these brief references to the machine question, it is not intended to convey the impression that it is of little consequence : in fact, the selection of the right machine is of equal importance with the designing of the tools and fixtures, and due regard should be given to this point.

In the manufacture of broaching tools, four factors play equally important parts—design, selection of material, heat treatment, grinding, and, if any one of this combination falls short of this equality, then you cannot expect to attain the full satisfaction possible.

When considering the design of broaching tools for surface broaching, it should be realised that such tools are nothing more nor less than a series of slotting, planing or shearing tools, and, if the designer keeps this point in the front of his mind, it will simplify his problem as to the question of the most suitable angles, clearances, etc., when reviewing the various materials and components he has to machine.

Broaching tools for surface broaching are usually made in short lengths for ease of manufacture and economical replacement, and for slab broaching they can be of very simple construction.

Referring again to Fig 5, already shown, these broaching tools were made up of nine sections, 8 in. long by $2\frac{1}{2}$ in. wide, each series of three having an opposed lead, in this case 15°, a back rake of $\frac{1}{2}$°, and a front rake of 8°.

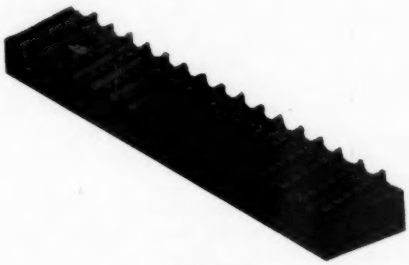

Fig. 10.

Fig. 10 illustrates one of these sections from which it will be seen that they are of a very simple character, being nothing more than

a flat section of steel with teeth evenly spaced, machined by a form cutter on the principle of machining a rack.

The next three figures illustrate how the broaches were designed to broach the steering arm referred to earlier in the paper, two components being machined at one time, and they show how broaches for machining complicated forms can be designed to allow of easy manufacture. This set of broaches was made up of five sections, three roughing and two finishing. The roughing sections, shown on Fig. 11, were made on the principle of a series of shearing tools, built up to approximately four sides of a hexagon.

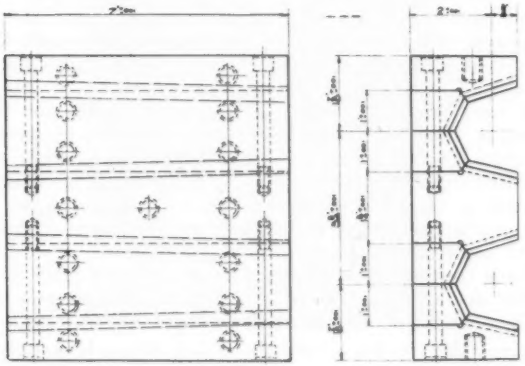

Fig. 11.

This form of broach was carried right through the three roughing sections, each section containing seven segments. Each set of segmets was 7 in. long, making a total cutting stroke during the roughing operation of 21 in., and provided for a stock removal of .270 in., reducing the component to within .002 in. of finished size at the lowest point. The three locating faces of each segment being parallel and square, the machining of them is quite straightforward, and to simplify obtaining the correct angle of the teeth, simple fixtures were provided.

The seating on the fixtures has an angle which corresponds to that of the teeth in relation to the base, so that the broach inserts can be ground on an ordinary Brown & Sharp type of surface grinder. Four of these fixtures were necessary to cover the whole series of broach inserts.

The shape of the component at the end of the roughing cut being approximately four sides of a hexagon, it is necessary now to make

provision to finish to form and size, and Fig 12 shows the layout of the finishing sections.

The highest points left by the previous broach meant that provision had to be made to take a depth of cut totalling .126 in. As these were only point contacts, it was possible to remove this stock in rises as high as .015 in. per tooth, leaving the last teeth finally to shave to form and size. As in the case of the roughing sections, these finishing sections were composed of segments, in this case five, the manufacture of which again was reduced to simple operations.

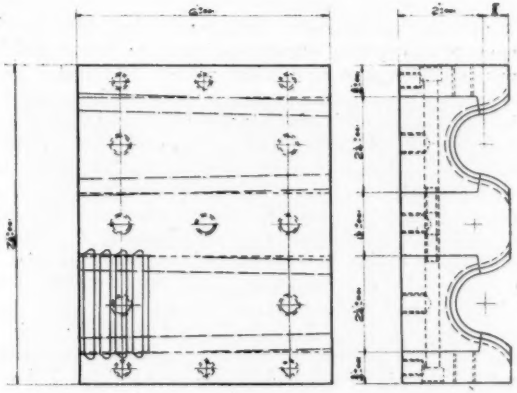

Fig. 12.

The middle segments were provided with centres to enable them to be ground cylindrically, and the end segments with a half centre, so that, when the two were clamped together, it enabled them to be ground in a similar manner. The two remaining segments were mounted on an adjustable angle plate, and ground with an internal grinding spindle.

When making broaches for machining two or more faces in relation to one another at one stroke, particularly if they are directly opposed, the load on one part may be greater than on another. Therefore it is essential, in order to avoid inaccuracies and variations in size, that the broach inserts should be encased in a holder of heavy section, preferably made out of the solid, to ensure rigidity.

Cast iron may be used in the case of the single purpose machine, as it is only necessary to fix this to the sliding member ; but, in the case of the dual machine, case hardened mild steel should be used, and provision for guiding the broach bar should be integral with the fixture, with the guide ways of the fixture also hardened.

The form and pitch of the teeth of course play a very important part in the design. The pitch is determined mainly by four factors—the design and weight of the component ; the nature of the material ; the amount of stock removal ; and the capacity of the machine, it being always borne in mind that the objective is to remove the stock in the shortest possible stroke, without in any way jeopardising the advantage of long set-up. Adequate allowance has to be made for chip clearance, but, as a general principle, the pitch should be such as to provide for a minimum of three teeth cutting.

It is desirable to reduce the pitch of the finishing section in relation to that of the roughing section by 20% to 30% ; and to reduce the back rake and the lead slightly, these having the effect of changing the sequence of the cutting edges, resulting in a better finish. When dealing with steel forgings or castings which call for slab broaching, it is a good plan to arrange the first section with steps of .010 in. to .015 in. per tooth, each tooth with a series of clearance slots slightly less in width than the cutting edges, every successive tooth being treated in a similar manner to cover the clearance in front. By this means, a first section of an average length, say, 7 or 8 in., with a pitch of, say $\frac{3}{4}$ in., can be responsible for removing easily .1 in., which is usually sufficient to dispose of the flash and any high spots which might be left on. Thereafter the rise can be anything up to .007 in., depending upon the factors mentioned.

There is no reason to hesitate to provide for a substantial rise per tooth during the roughing operation according to the nature of the component, for it is proved that a greater force proportionately is required as the size of the chip decreases, there being a very sharp rise for chips below .005 in., because the finer cut causes a wedging action on the tool.

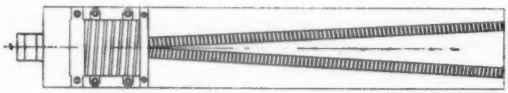

Fig. 13.

In designing tools for use on cast iron, when the design of the component so lends itself, the roughing portion of the broaching tool can be arranged in such a manner that each tooth cuts to the full roughing depth, as in the manner of a gang planer tool, with a finishing section arranged to cover the full width of the job, as shown on Fig. 13.

This of course is a very economical and effectual method, but slab broaches built up in sections, with an opposed lead as illustrated

on Fig 5, are capable of more universal applications. While it is possible to establish some sort of standard form of tooth, it should be used only as a guide, and not regarded as having to be rigidly adhered to. It is recommended, particularly in the case of steel, that the tools should be set up for trial before being put into production, to ascertain the type of chip produced.

It should be the aim to get the chip to curl—the tighter the better—and the fact that it is easy to provide the teeth with a shearing angle, combined with the use of a curved lip tooth graduated to suit the conditions, makes it possible to achieve this, and it has been proved that the effect is also to reduce the force required to remove the stock.

Fig. 14 shows an enlarged view of such a tooth, and the type of chip produced on 40 ton steel.

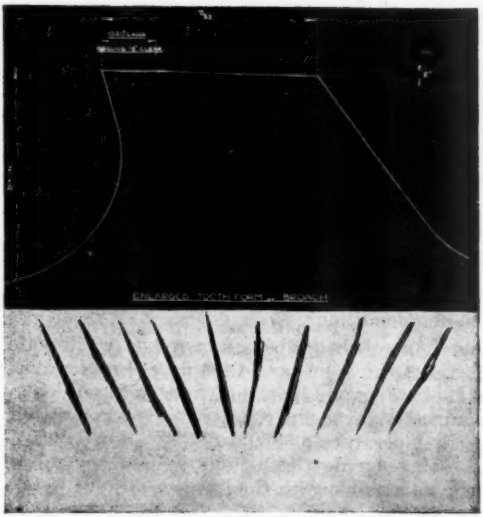

Fig. 14.

You will note that the tooth is a fairly heavy section ; it has a shear angle of 15°, and has a lip which is slightly curved. The top clearance is composed of two angles, the first half degree having a land of .040 in., and the remainder run off at 2°. There is of course nothing revolutionary about this. It was purely a question of carrying out the recommendation made earlier in the paper,

to apply the same principles which proved satisfactory in the use of shearing and other cutting tools.

The selection of material from which to make surface broaching tools is, as indicated, of equal importance with design, and, while there are a number of varieties of materials used for making cutting tools, in the case of broaching, the two which have been most widely used are case hardened mild steel and high speed steel. However, as experiments with case hardened mild steel have not as yet proved very successful in surface broaching, owing to its inability to stand up to the high cutting speeds now used, high speed steel is almost universally accepted.

There are of course many grades and qualities of high speed steel, but that selected should be made from the very best materials, a typical analysis of a high grade high speed steel being :—

Carbon	.65% to .75%
Tungsten	18% minimum
Chromium	4%
Vanadium	1% minimum

but, in order to obtain consistent results, as regards both hardness values and cutting properties in the finished tools, it is desirable that the carbon content of the steel should be within much closer limits, say .69% to 72%. It is only in the very highest grades of high speed steel that the carbon content is controlled within such fine limits.

It should be specified that the steel be cast into sufficiently large moulds to permit of a forging reduction of area by hammering of at least 95% from the ingot to the finished bar size, in order to break up the brittle carbide structure which is formed on cooling from the molten condition.

Preferably the steel should be hammered in two directions, that is, across the axis of the ingot, and then upset and hammered on end into the form of hammered blanks. After forging, the bars or blanks should be annealed by being reheated slowly in a closed annealing furnace, to a temperature of 850° to 930°C., for a sufficient period to ensure heating evenly throughout, and afterwards allowing to cool as slowly as possible with the furnace.

This treatment, particularly the slowness of the rate of cooling, has a very great bearing on the machinable condition of the material and, if carefully carried out, a Brinell hardness of 220 to 240 should be obtained. Fairly heavy sections should be used for broach inserts, because they have to be fixed in some manner to the broach bar, and thin sections do not allow sufficient surface for securing. Where quantities are large, and long set-ups are desired, then tools tipped with tungsten carbide can be justified. There are records of such having five times the life of high speed steel in surface

broaching. High speed steel for roughing and tungsten carbide for finishing can well prove the happy medium in such cases.

Heat treatment being again an equally important factor, it is necessary, if you do your own treatment, to equip that department with satisfactory facilities for ensuring that the various recommendations as to treatment made by the respective steel makers can be carried out. For the high speed steel referred to, the heat treatment recommended after machining the steel is as follows:—

For hardening, the tools should be brought up very gradually to a pre-heating temperature of approximately 850°C., preferably in a furnace which is designed to prevent decarburisation, this being the cause of soft skin. The tools should be maintained at this temperature for sufficient time to enable them to become thoroughly and evenly heated through, after which they should be transferred singly to the hardening chamber proper, which should be maintained at a temperature of 1300°to 1310°C.

The tools should be kept in this chamber until they are well up to the heat of the furnace, and then withdrawn, and quenched in oil or cooled off in air, the former method being preferred, as there is less liability to damage from scaling. The tools should be left in the oil quenching bath until they are cooled to approximately 100°C. or a little less. They should then be given secondary hardening treatment by being transferred to a tempering furnace or bath, and brought up to a temperature of 550° to 600°C. After having become evenly heated throughout, the tools should be withdrawn, and allowed to cool normally in air, in a dry place. From the foregoing it will be realised how essential it is that adequate provision is made for heat treatment, in order to secure that degree of toughness, combined with hardness, which will ensure the tool's withstanding the shocks and maintaining its cutting edge.

Since grinding is the last stage in the manufacture and is the final operation before the broaches are put into use, it is allowable to stress again that this is equally as important as the preceding stages of manufacture, and demands the same care and attention. The matter of grinding, however, need only be dealt with in relation to the grinding of the teeth themselves. The first point to note is that to ensure high finish on the component, and maximum life of broach, a fine finish on the teeth is essential.

No very special equipment is necessary beyond that found in the ordinary toolroom, providing of course that amongst the grinding plant is a machine with a wheel head movement that can cover the surface of the work table ; but in the event of this not being so, such provision must be made.

A work table with a travel of 48 in. is an advantage, as the broach inserts can in some cases be finally ground set up in the broach bar ; but, if the location points are accurately made, this

is not essential. The machine should be equipped with two wheel heads, one to grind on the periphery, and one to use the face of a cup wheel. In both cases, the wheel head should be of the plain bearing type, with adequate provision for adjustment, particularly in respect of end play. A spacing device is also desirable, so as to assist in the blending of the teeth.

The front of the tooth can be ground with a straight wheel having the face shaped to suit the form of tooth required, but it is not desirable for the clearance rake to be ground on the periphery of a straight wheel, unless the wheel is dressed for every tooth, or a different portion of the face of the wheel is used for each tooth. Even then, if there is a fair amount of stock to remove, corrugated grooves may occur, and it is possible for the cutting edge to be below the supposed clearance part of the tooth. By using the face of a cup wheel, this possibility is obviated, with the additional advantage of taking the heat away from the cutting edge.

Where the face of the broach is made up of more than one segment, inspect the sections in the broach bar before they leave the grinding machine, to make sure that the teeth do blend, and that one is not ahead of or behind the other, or the chip clearance at that point where two sections meet is not stepped, as these are traps for chips, which would not only affect the finish, but may be the cause of teeth breaking. Further, every tooth should be inspected separately, remembering that each is an individual cutter, and that one bad tooth can be a constant source of trouble.

The designing of fixtures provides many opportunities for ingenuity, which should be devoted towards simplicity and rigidity, both of which are of major importance, as the first can affect the loading time, and the second the performance and life of the broach. When the broaching operation is the first machining operation, the general principles of fixture design apply, with the special proviso that one clamp should be in such a position as to resist the pull of the broach. There are, however, many occasions when nothing more than location points are wanted. In such a case, cast iron with hardened location points is satisfactory, but in the case of fixtures where clamping is necessary, steel is preferable to cast iron, and cam or toggle operated types of clamps to screws.

As the piece must be lifted away from the broach, fixtures should be arranged to receive the component in the most suitable position to allow of easy removal. A good plan is to make provision for the fixture to swivel. This will allow the broach to be returned during the unloading process. A further point which should be taken into consideration is that of presenting the component to the broach in the most suitable position to assist the load and the cut. Where the component is of a fragile nature, or a very awkward shape, a fixture in the form of a mould, or say a reproduction of

the die, cut away where the face has to be machined, and relieved where necessary, particularly at the flash points, can be used to advantage.

The locating and clamping portion of such a fixture should be split into two or three sections, according to the shape of the component, one section being a fixed point for location, and the others forming the clamp, and taking care of forging variations.

Many more ambitious fixtures than those dealt with, incorporating hydraulic or mechanical clamping and indexing, are of course in use. In such cases, it is possible on some machines which are hydraulically operated to arrange for an auxiliary supply to operate a clamping device, or maybe to arrange a series of dogs on the broach bar, to clamp, unclamp or index the fixture ; but these are points which call for close co-operation between the manufacturer of the machine and the tool designer. One or two examples of what such co-operation can achieve may be of interest to you (Fig. 15).

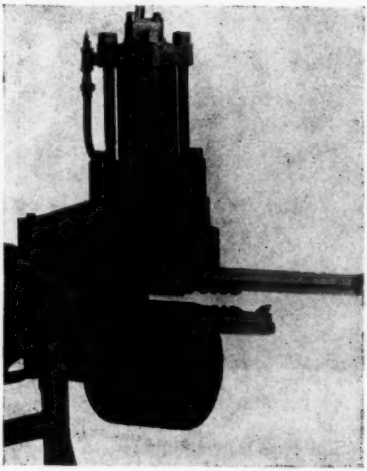

Fig. 15.

The first proposition was to machine the flash on steel liners which had been welded. Fig. 15 shows the fixture mounted on the face of a horizontal machine. The fixture is hydraulically operated, and is arranged in series to work semi-automatically, so that, on the operator depressing the hand lever, the fixture cylinder moves

down lowering the upper cutter bar into the cutting position, and at the same time clamping the liner in the fixture with sufficient force to straighten the component for broaching. The cycle then proceeds, the cutting in this case being done by pushing instead of pulling, the broach returning, and the cylinder unclamping, so that the operator has only to load and unload. These facilities enabled a production of 480 pieces per hour to be obtained.

The second example illustrates how a wide range of wedge gate valves, each having a double slot, ranging in size from 2 in. to 10 in., was accommodated on a universal fixture, also of a semi-automatic character. (Fig. 16).

Fig. 16.

A hydraulic cylinder, again connected in series, is used to raise and lower the valve locating and holding fixture, of which two are necessary to cover the range of sizes. When the fixture is in the upper position, the operator loads and unloads the work, and when it is in the lower position it is ready for the broaching operation. Broach guides for each of the cutter bars are provided, with adjustment to take various sizes of cutter bars to suit differing slots in the valves and these are capable of lateral adjustment to take care of varying widths. Such layouts do, of course, call for courage on the part of the designer, owing to their high initial cost, but it must be

remembered that the machine's only productive time is when it is broaching, and, as the average cutting time in surface broaching is often below ten seconds, the return speed being usually half this, such courage will be repaid in results.

High cutting speeds have been mentioned, and the range of speeds used in surface broaching on various materials will particularly stress the necessity for rigidity of fixtures and simplicity of clamping devices.

For broaching nickel; chrome; vanadium; molybdenum; and high carbon steel, properly annealed, and not exceeding 248 Brinell—speeds from 12 to 20 ft. a minute.

For ordinary mild steel, or low carbon steel—speeds from 16 to 30 ft. a minute.

For cast iron of low strength—speeds from 20 to 35 ft. a minute.

For cast iron of high Brinell—speeds from 16 to 25 ft. a minute.

For brass and bronze—speeds from 25 to 35 ft. a minute.

This table can be taken as perfectly safe for estimating purposes, when using high speed steel of the quality referred to, and machining an area of approximately 6 to 8 in., the principle being of course the harder the material, the lower the speed, though a cutting speed of 8 to 10 ft. a minute is being used successfully on 85 ton steel.

Cutting lubricant, as in other forms of machining, plays its part in the successful performance or otherwise of broaching tools. For average stock removal, where the load on the tool is not relatively high, or the heat liberated is not of much consequence, any good mineral cutting oil, tested and adopted in normal machining practice, is satisfactory; so, providing that this is of good quality, it can be a matter of personal selection as to make. But if it is desirable to make some improvement, or if it is found that the cutting oils normally used are not giving you the expected life of broach or finish, then rape oil or sulphurised mineral oil should be tried. But instructions should be given that the tank is well cleaned out before any new oil is put in.

Cast iron generally is broached dry, but where a lubricant is necessary, as might be the case when broaching iron with a very high Brinell, say, 35, the sulphurised mineral oil mentioned will be the most satisfactory.

For brass and bronze, paraffin oil with the viscosity increased by the addition of a good quality soluble oil, in the ratio of 6 to 1, is recommended, though this type of lubricant should be delivered at low pressure, to avoid the offensive and injurious spray which would otherwise occur.

One more point on cutting lubricant—do not use a trickle: provide a good flood, with a nozzle designed to suit the job, to allow the maximum amount of lubricant to get to it. It will help to dissi-

pate heat, preserve the broach, and reduce the necessity for cleaning it. It is also a good plan, wherever possible, to have an additional nozzle behind the cut, as well as in front, directed at that point where the broach is leaving the component.

In concluding, reference may be made to the opening remarks of this paper, when the view was expressed that in a relatively short time suface broaching would find a place in all branches of the engineering industry. Therefore, in this paper I have concentrated on the possibilities of the more universal applications, and have endeavoured to make it clear that, provided you have selected your machire correctly, and given due attention to the tool and fixture requirements, there are comparatively few difficulties to contend with other than the question of excess stock removal, which in common with all other forms of machining has an effect upon the production : and when the initial handicap of capital expenditure has no longer to be reckoned with, and surface broaching machines have become part of standard plant equipment, it will be necessary only to apply ordinary shop knowledge and experience to ensure success in the innumerable cases where the advantages of surface broaching justify its adoption.

Discussion—London Section.

MR. E. J. H. JONES: No one will dispute the credentials of our lecturer this evening to speak on this particular subject. Among other things, he is known as an authority on surface broaching. He has painted an intriguing picture of rows of broaching machines working away whilst production engineers for fifteen months at a stretch, are fast asleep—also in rows— I take it. I might ask him if the production engineer asleep is essential to the satisfactory working of the machine or may we just sit around and read books or go fishing?

He has wondered why surface broaching has only recently become recognised as one of the standard methods of production. I think it is because we had available the milling machine which under certain circumstances was a comparatively fast producer of external forms—whereas the slotting machine, slow and comparatively inaccurate, was responsible for the necessity for internal broaching in order to bring the operation within the limit of commercial economics. We therefore, in my opinion, tackled the more difficult problem first. I do not believe that any one with broaching experience will dispute the contention that it is more difficult to broach internal than external forms.

With internal broaching we have always with us the operation on which the broach repeatedly seizes in the hole, we also have the internal form around which there are irregular sections with the result that some portions down the length will tend to move away from the cutting teeth and spring inwards after the broach has passed through. These troubles are very difficult to overcome and are not met with to the same extent on external broaching. Also, due to the design of certain types of machines, keeping the cutting compound in the hole represents considerable difficulty.

Whilst as we all know broaching is successfully applied to ferrous and non-ferrous metals, in common with other machining operations, excluding grinding, material that is too hard cannot of course be satisfactorily broached. This factor must be considered carefully particularly as the broach is one of the most expensive of the cutting tools, also whilst material that is too soft or luggy will tear leaving a poor finish on the work and often causing fracture of the broach teeth by crowding the gap between successive teeth, the material being in such a condition that it will not curl into a chip. I have found that the best results with steel are obtained when the metal is between 3-8 and 4.2 Brinell limits of hardness, in consequence a heat treatment operation is often required to bring the material to be broached into this condition.

I have found particular difficulty in broaching internally white-heart malleable iron due to the tendency for it to harden up towards the centre and become patchy, although much better results were obtained from blackheart. I should like to ask our lecturer if he has had any experience with surface broaching these materials.

One point in broach manufacture which cannot be overstressed is the importance of grinding the cutting edge very smoothly. I have information that the broaching costs, that is the number of pieces broached with one broach before the tool was used up, was 12 times greater in one organization than in another and it was ultimately proved that rough grinding on the teeth was mainly responsible for the poor figures of the one organization.

Our lecturer has stressed the necessity for using the right cutting compound. I have found that rape oil will give much longer life and a better finish than sulphurized mineral oil. I might stress the point that it is essential that no adulteration of the rape oil takes place. I have ascertained on several occasions when broaches have seized during internal broaching that the cause has been the inclusion of mineral oil in the cutting compound, often as little as 3% causing trouble.

I incline to the opinion that on batches of 100, especially if the batches recur every week or so, the cost of broaches would be uneconomical, but I believe there is a big future for surface broaching in the smaller engineering shops i.e., those producing in recurring hundreds, for a slab broach 6 in. or 8 in. in width, the same broach being used to machine surfaces on a number of different components, especially if batches of 100 occur several times weekly, this would be quite an attractive proposition.

To make surface broaching really attractive, as our lecturer has emphasized, much more uniform stampings and castings are required. Suppliers at the moment are not anxious to produce a better class of stampings, they have plenty of orders and are at the moment satisfied in producing components, the majority of which will just about pass the purchaser's View Room. Offshot stampings and irregular flash lines are already a bugbear in machine shops and for a broaching proposition where the number of teeth available must bear some relationship to the amount of material to be removed, regularity of machining allowance is essential.

One other question which I would like to put to our lecturer is what shear angle has he found to be most satisfactory for various materials ?. The lecture this evening will I am sure do much to stimulate interest in surface broaching, and I should like to congratulate Mr. Weatherley on the manner in which he has presented it, avoiding as he has done any exaggeration.

MR. WEATHERLEY: Mr. Jones has raised some very interesting points, some of which are in the nature of extremes. I agree that broaching internal forms presents more difficulties than broaching external forms, mainly because of the greater difficulties in the manufacture of the broach. He has also mentioned the extremes of very hard and very soft material, but the fact that you are able to provide teeth with a shear cut (and I am sure that no one will deny that removing metal by a shear cut is advantageous) providing the material is machinable, favours surface broaching.

I do not agree that batches of 100, even though they recur only every week or so, are necessarily uneconomic, as I had in mind, when making this statement, a condition such as Mr. Jones visualises. There is no doubt that a slab broach 6 to 8 in. in width can cover a very wide range of components, and I maintain that the possible advantage of being able to have a machine necessitating only the changing of work holding fixtures, instead of the whole tool set up, can be a more economic proposition.

While this paper deals only with surface broaching, the troubles, all of a different character, that Mr. Jones is experiencing in internal broaching—that is, broach seizing in the hole, broaching of irregular sections, and of whiteheart malleable iron—can, I believe, be minimised by the application of the same principles as those governing the design of tools for surface broaching. I presume also that the difficulties referred to occur mainly, if not wholly, in the broaching of round holes, as I should question whether many of such troubles have been met when broaching a series of splines internally.

A spline broach is a good example of the fact that a broach is really only a series of slotting tools and, if the tooth on a round broach is broken up to conform to this principle, leaving the finishing end to size only, this will, I think, help considerably in all the cases to which he refers.

I would add that, in laying out the broach in this manner, each tooth should be given sufficient work to do. There is danger, if the rise per tooth is too small, that when the keen cutting edge is gone, instead of cutting you are in effect trying to pull a long taper burnisher through a hole, which has already been made taper by the metal removal before the load on the broach built up to the point where the component just wraps itself round the teeth and becomes solid.

Mention has been made that a broaching tool is one of the most expensive of the cutting tools. I agree it is higher in first cost but, in the majority of cases, on a tool cost per piece basis, it not only shows a direct saving, but if all the savings effected indirectly were added, the resultant figure would amply support my contention.

I am glad to have Mr. Jones' support as to the importance of grinding, and the desirability of more uniform stampings and

castings, and despite the difficulties mentioned, brought about by the prevailing conditions, I do stress the necessity for persistence in this matter. I recall one component under consideration for surface broaching which, owing to the excess of material consequent upon bad forging, would have required a broach with 94 in. of cutting stroke to remove the stock.

Mr. Jones asks what is the most satisfactory shear angle for various materials. I will repeat that portion of my paper in which I said that, if the designer kept in mind his experience on shearing angles with shearing, slotting, and planing tools, he would not go far wrong. Broadly speaking, cutting angles for soft and hard cast iron vary respectively from 2° to 10°, and 15° for steel. But the shear angle on flat broaches varies with the width of the tool to provide overlap of teeth in work, regardless of the material being broached. Where the face being broached is a narrow one, this prevents the entire edge of one broach tooth from leaving the work abruptly before the next one is engaged. This helps to provide a more uniform load on the machine.

Mr. F. White: I was very interested in Mr. Weatherley's comments regarding broach manufacture, and he mentioned that it was quite easy to undertake the grinding of broaches in the average tool room, but I was rather wondering with regard to broaches about the question of hardening in the average tool room, particularly when he refers to a broach of something like 48 in. long, unless, of course, it be a built-up broach. There is one other factor with regard to this hardening of broaches. My small experience with broaching is mostly internal, and I remember well efforts at trying to harden them and having them come out something like a donkey's hind leg. I wonder what method he advocates for straightening broaches after hardening. Also the question of adjustment or backing up after grinder cuts on the normal type of internal broach, say, a slotting broach. In my experience it used to be backed up by means of a backing piece which can be ground or cut to suit the grinding. Now, how do you cater for that? Presumably there must be some form of adjustment.

Mr. Weatherley: I rather wondered if this would develop into a discussion on internal broaching, and not surface broaching. To answer the question about dealing with the problems of hardening, straightening, and grinding broaches—broach inserts (as we should refer to them) for surface broaching are usually made in short lengths, and I doubt if there is any broach maker who would exceed a length of 9 in., except in very special circumstances. Therefore, no difficulty in dealing with such short lengths should arise in the average tool room with regard to hardening and grinding. As far as straightening is concerned, if ordinary care is exercised, there should be no necessity for this, but if occasion does arise, then the

section would have to be re-heat-treated, and straightened before the core is cold. This is a matter on which your steel supplier should be consulted.

Respecting adjustment after re-grinding, if adequate supervision is maintained to ensure that the broaches are not kept in use after they have become dulled, it should be necessary to remove only approximately .001 to .002 in. from the face of the tooth to bring back the keen cutting edge. Such supervision can be rewarded by as many as 20 re-grinds, though 10 to 15 is looked upon as the average, and unless the limit is a very fine one, the broach should still be cutting size.

Regarding renewals, as the average number of pieces between re-grinds, taking the examples given in the paper, varies from 2,500 to 200,000, this is not a very acute problem. When, however, the time does arrive for renewals to be required, speaking generally it is necessary, on the first occasion, to scrap only the first roughing section and renew that section immediately in front of the finishing section as, unless a very high degree of accuracy is being asked for, the finishing section usually outlasts the roughing section by two to one. In the case of just a flat slab broach, provision is made on the machine used exclusively for surface broaching to permit of adjusting the work fixture table to compensate. In the case of the dual purpose machine, as explained, this provision must be made in the design of the fixture, and I would lay stress on the undesirability of the employment of shims.

MR. R. KIRCHNER: I would like to challenge some remarks Mr. Weatherley has made on the simplicity of broaching the oval hole in the big end of a conn rod. I think the oval hole is due to the fact that you have to make an allowance for splitting and after splitting the two halves come together to make a round hole. The fixture as I remember, and as I believe you explained it, was a peg or plug locating in the small end by some means locating the other end radially. I cannot help feeling that if you wish to maintain the centre distance between the big end and the small end you would have to have some means of guiding the broach, otherwise the broach would be piloted by the pilot on the front end and after that would just follow the previous hole; and if there should be a hard surface on either side of that actual hole it is likely to be deflected. It is quite possible that my next question will be ruled out as being facetious. I would very much like to know the relative cost between the set of five broaches for broaching the steering arm and, shall we say, a pair of milling cutters? It seems to me on looking at the construction of these broaches that they are very expensive items. I would also like to know in connection with these broaches whether after you had ground them they were of any further use, particularly the finishing broach.

With regard to the remark you made when referring to fixtures, that it is preferable to have steel fixtures and not cast iron, I would rather like to differ. It has been my experience that on milling fixtures, particularly large milling fixtures for very heavy operations, a really heavy casting is more practical than steel. Another point which might seem very small—do you make the broach to the actual size of the component? I have met cases where the same broach pulled through two different materials would produce a different size hole. Could you give us any data on that? My point is that you could make a broach of 1 in. square and pull it through brass, then through gear steel, and you would find the size of the holes different.

Looking at broaching from the point of view of one who is enthusiastic on milling, and milling cutters, you will find that you run into trouble on soft materials. There is one soft material that interests me at the moment very much and that is electron. Can you give us any data on broaches for broaching electron? It machines very fast on milling machines and I should imagine for a suitable comparison of the figures you give us that it would be similar to lightning. Please excuse me, Mr. Weatherley, do not think I am trying to be awkward, but you did mention that the best results can be obtained if castings and forgings are kept to very suitable limits—well, in support of milling machines and cutters, I would like to say that the same thing applies to milling, except that you have two or three roughing operations, where we cut out the same job in one operation.

MR. WEATHERLEY: In broaching the oval hole on the connecting rods, provision is made to hold the broach rigidly at each end, and guide it accurately throughout its stroke. By this means it is necessary only to fix location points in relation to the centre line of the broach. With regard to the cost of the broaches for the steering arm, and whether they are of any use after they have been re-ground so many times that they have lost their size and shape—in the case in point, it was only possible to produce the component otherwise by the profile method, and the tool cost per piece was 77% in favour of the broaching tool. Broaches of special form or shape, after they have lost their size or shape through re-grinding, like any other cutting tool, are useless for the same job.

As regards the question of steel versus cast iron for fixtures, the preference indicated for steel was not on account of the question of vibration, as this in surface broaching is of little consequence. In surface broaching the fixture is subjected to a continuous load, 20,000 to 30,000 lb. being frequent, added to which a broaching fixture gets twice the amount of work that a milling fixture gets, owing to the increased loading and unloading operations. Answering

the query as to whether the broach is made to the actual size of the component, the reply is yes, or to the mean of the limits requirement of the component. If the component is of a very fragile character, care should be taken to ensure the minimum of load at the sizing end. But speaking generally the broach should be able to reproduce itself within commercial limits, say, to .0005 in.

I have had no experience as yet with the broaching of electron, but, judging from the nature of the material, it should be possible to cut it up to 100 ft. a minute. With regard to the question raised, if the stock removal is such as to be beyond the stroke capacity of the broaching machine, therfore requiring two operations—each case must of course be taken on its merits, but in the majority of cases, it can be said that the nett results are favourable to surface broaching.

As an example, let us take a mild steel forging with a reasonable amount of stock for removal (and I would agree that $\frac{1}{8}$ in. is reasonable), with an area of 6 to 8 in., this could be broached in approximately 24 in. of cutting stroke, at a cutting speed of around 20 ft. a minute, so that the cutting operation would be completed in six seconds. If the amount of material was doubled (and assuming the maximum stroke of the machine is 24 in., though machines with longer strokes are of course available), by using a two spindle machine, or taking two cuts, you would have finished the two cutting operations in a time of twelve seconds, to which must of course be added loading and unloading time, which approximates to the same as milling.

A VISITOR: Could Mr. Weatherley tell us whether there is any difficulty experienced in surface broaching two faces at right angles, where the apex of the right angle comes forward towards the broaching cutters, due to the shearing angle put on the tools?

MR. WEATHERLEY: No difficulty whatever, providing that the lead on each face is such as to take the chip away from the apex.

MR. G. H. HALES: After listening to our lecturer's paper, I think he has made a good caxe for surface broaching, as applied to quantity production only. Mr. E. Jones has ably supported his case—re quantity production—but did not agree with him re small production quantities. I think most production engineers would like to find out where and when surface broaching is an economical proposition by comparison with other methods of machining and Mr. Weatherley has given us very little information of this kind.

In our lecturer's opening remarks he made reference to surface broaching as being economical for batches of 100 pieces, but he has given no information to support this statement. I consider the case for surface broaching, or otherwise, is purely a question of economics, from the production engineer's point of view. In the figures given by our lecturer, as far as I remember, the least

number of pieces produced in any of the examples shown, was 100 per hour. Therefore, batches of 100 represent one hour's machining time only, but, I suggest that tool equipment cost might be the controlling factor for consideration.

In dealing with plain surfaces, I can visualise plain surface broaches taking care of operations on a number of different components and, therefore, suitable adjustable fixtures might be set up for the different sizes required. But, again, in batches of 100 we are up against one of the things which appear essential to economy in surface broaching, that is, minimum allowance stock removal on stampings or castings, and I contend that in small batches of 100 we cannot afford to pay the price asked by manufacturers to supply castings or forgings to close limits of machining allowance—in this country at any rate.

We can visualise an extreme case of dealing with small batches which do not repeat, where even assuming surface broaching time was one hour only, against twenty-one hours by another method of machining—assuming the latter method simple tool type—when the broaching method might be less efficient due to the tooling cost entailed. To surface broach slots or contours would appear to entail a heavy tool expense item, for new broaches, guides, fixtures, etc., for every set-up, and in this connection, I should like to see comparative costs of broaching and other machining methods —such as milling—on small batch production.

To determine whether to surface broach or to mill, it would appear necessary to consider: The type of component to be machined and the limits of accuracy, and finish required; the number of components required in a given time; comparative cost—capital outlay—on broaching machine and milling machine; cost of necessary broaches and fixtures by comparison with milling cutters and fixtures; comparative production times obtained by broaching and milling.

MR. WEATHERLEY: Mr. Hales has selected from the early part of my paper reference to batches of 100. As I explained in reply to Mr. Jones, the suggestion of batches of 100 being economical was touched upon in connection with long tool set-ups, when, if it is possible to select a number of components to suit the tool set-up, it is no longer a 100 batch, but 100 multiplied by the number of different components, and it can resolve itself into the changing of work holding fixture only. With regard to the disadvantages of buying materials and components in small batches of 100, I agree that, where it is not a standard or a recurring product, castings or forgings may have to be used; but this is not necessarily a handicap any more to surface broaching than to milling, as my reply to a previous question indicates that two broaching operations can prove as economical as one milling operation.

MR. BEADLE: I would like to ask Mr. Weatherley if he can give some figures on the pressures to carry out this work. The only reference I saw in the paper was the chart shown on the screen which gave some very high figures. I would also like to ask whether he considered the hydraulic method to be the only successful one and whether he includes the hydraulic equipment as part of the machine, or whether one could employ a hydraulic accumulator to supply batteries. Could I just amplify that by saying that there were some very high figures for broaching 1 in. and you were talking of 6 in. broaches?

MR. WEATHERLEY: Mr. Beadle did not apparently quite understand the slide and explanation dealing with the forces required for broaching. It would be explained that the figures on the chart only represent the constant, which, taken in conjunction with the cubic content of the chip, establishes the force required to push the broach through. In answer to his second query—the hydraulically operated machine is considered to be one of the prime factors in the success of surface broaching. Respecting the question of being able to use a hydraulic accumulator to operate a battery of surface broaching machines, this would not be a practicable proposition.

MR. SCAIFE: I think we all agree now that surface broaching on large quantity production such as you are getting in an automobile shop is a paying proposition. Mr. Weatherley has been trying to make out—trying to prove—that it is also an economical proposition on small quantities. I have not been satisfied with Mr. Weatherley's answers to various points on that score and I should be more satisfied if Mr. Weatherley worked out an analysis of the cost in both cases, that is surface broaching and milling. I figure it out that with one of Mr. Weatherley's machines the overheads on a machine like that would be somewhere in the nature of £9 a week, that is for obsolescence and depreciation such as the usual machine charges you pay, as against probably one-third that with milling. That of course does not include the assistance which I visualise would have to be behind surface broaching. Mr. Weatherley mentioned in his paper one broach at work, one in the store, and another broach being ground, which rather signifies an expensive organization. Taking some of the small quantities I can quite imagine the operation time would be very small, but when you have got to take out of the machine these heavy broaches and transport them to the stores and then bring them back to the machine, I can quite imagine you are going to lose quite a lot of expensive time. I have not figured it out, but I am always rather suspicious about these expensive equipments on small quantities.

Recently I have had an experience with such equipment. I bought a second-hand planer for £200 and I bought another new planer

about the same size for £3,000. Of course the new planer simply took off the metal at a tremendous speed, but the second-hand machine is much slower—the machining rate is only about one-third the time—but the cost of planing is very much less on the second-hand machine than the modern high-speed planer. Of course if you cannot keep these expensive machines properly employed and continuously employed the range between the times very often more than offsets the advantage you gain by the low cost of the actual operation. I wonder if Mr. Weatherley has ever analized the two cases and worked it out in small quantity production on those line ?

MR. WEATHERLEY : I am sorry that Mr. Scaife, although he is in agreement on the advantages of surface broaching for large quantities, is still not satisfied with regard to the economic side for small quantities. If the circumstances were such that £9 was the figure allocated for obsolescence and depreciation, it would indicate that the machine was installed in a factory where high production and large quantities were the order of the day, and in consequence any such figure, if it was against the surface broaching machine, would be counterbalanced by lower tool and production costs. In the case where small quantities have to be budgetted for, there is available, as I indicated in my paper, a dual purpose machine, which can be used for both internal and external broaching, and the figure mentioned of £9 a week would in one year about meet the full capital cost of its installation. With regard to the question of the three sets of broaching tools referred to on the conn. rod job, I thought it had been made clear that this was done, not of necessity, but as a convenience, and as a matter of good organization. Regarding the time taken for the changing of tools and fixtures, this should be no more nor less than in the case of milling.

MR. EDWARDS : Mr. Scaife raised the point concerning the necessity for three sets of tools. I am able to give a little information about this, as by coincidence, I was in the works this afternoon where the operations on the conn. rods are being performed. During part of the discussion, there has been a tendency I am afraid to consider small lots of 100 components rather than the much larger quantities, which a job like the conn. rods represents. The machines operating on these are working continuously every day, and sometimes at night, and therefore three sets of tools are kept as a matter of expediency. These tools have been in operation since about last August or September, and the company's policy is to change them once per week. Three sets are used therefore so that it is possible to have one in the machines, one in the tool room for re-grinding, and one in the stores. I can tell you this, which perhaps Mr. Weatherley does not know, there are hardly any visible signs of wear on these tools yet, although they are producing 2,500 sets of

components per week, so that at this stage one cannot say when these tools will wear out. When you have such an enormous production the question of duplicating tools hardly arises, and the ultimate tool cost per piece is practically negligible.

MR. PUCKEY: Those of you with short memories and shorter membership will probably not know that Mr. Weatherley was for many years a prominent member of our Council and also a President of the London Section, and I am personally very glad to see his cheery face before us again, particularly when he brings a paper of such interest as surface broaching. I think you will agree that he has broached the subject very well, but I must say that although Mr. Jones and a few others instantly dived below the surface and got to internal broaching very quickly, Mr. Weatherley has, I am sorry to say, only remained on the surface as far as economics are concerned. It has been dealt with by Mr. Scaife and Mr. Hales, and I would insist that we production engineers must consider the economics of the situation very considerably before we change over from one method to another. We do not usually make a changeover because a thing is picturesque or new, but presumably because it possesses a certain economic value, and in this new process we are entitled, I think, to consider these very important facts before we change from established methods such as milling. I think Mr. Weatherley would have helped us by showing an analysis of these differences on the screen. Six hundred an hour sounds very attractive no doubt, and on those particular parts shown the figures are very attractive, but facts are facts, and it would have been extremely interesting to have seen those facts put down in some sort of order with due regard to obsolescence, depreciation, wear and tear and all the rest of the facts that have to be considered. But my primary object is to propose a vote of thanks to Mr. Weatherley and I do so because I have learnt something to-night and I shall leave this room with more knowledge than when I came into it. I am sure you will agree with me when I say that we all owe Mr. Weatherley a very hearty vote of thanks for his exceedingly interesting lecture this evening, and I would like you to show this in the usual way.

MR. WEATHERLEY: Thank you, Mr. Puckey, for your very nice remarks. I am very sorry that I have not presented detailed figures of machine and tool costs, etc., as I frankly did not think it necessary, taking it for granted that, with all the production figures and information included in the papers, members would be able to compare them with their present methods.

Considered reply by Mr. Weatherley on questions raised regarding economics of surface broaching.

Despite the special attractiveness of any particular form of machining, the question of economics is, of course, a determining factor

to be considered before any new installation is decided upon. Therefore, the comparisons with their accompanying amplifications, of the four examples shown, taking only the straight issues of capital, tool, and labour costs, will answer in particular the points raised by Mr. Hales, Mr. Scaife, Mr. Puckey, and others, on this question. Taking the five examples in their order, therefore, first the steering arm, it was only possible owing to the contour of the three radii made, to produce this by profile milling, and further, owing to the severe call it made upon the cutter and the spindle bearings, it necessitated a heavy type of vertical milling machine, the production requirements of 100 per day prior to the adoption of broaching being such that two of these machines, working two and sometimes three shifts, were able to cope with it.

On production requirements increasing to 200 per day, new methods were investigated, before installing any more machines, and it was found that one broaching machine, suitably tooled up, could take care of the whole of the production.

Probably the firm would not have installed nine milling machines to meet these requirements, but would have worked three shifts, so it is on the latter basis that the comparison is made, though the extra labour costs so involved by night shift rates have been ignored.

STEERING ARM—PRODUCTION REQUIREMENTS 200 PER DAY.

	Broaching.	*Alternative.*	*Approx. saving.*
Capital cost	One mach., broach bar, fixture. £858.	Three mach., fixtures. £2,460.	65%
Tool cost	£185 for 140,000 max. .31d.	£9 for 1,500 max. 1.44d.	77%
Labour cost	100 per hour at 1s. 6d. .18d.	Three per hour per machine at 1s. 6d. 6d.	97%

This installation has now been running for eight months, and the tools are now due to come out for their second re-grinding. During this period approximately 40,000 components have been produced, removing stock $^{5}/_{16}$ deep on face 1.681 long.

The plunger pin—the production required previous to the adoption of broaching was 1,000 a day, and the machines used were three knee and column type milling machines. The pieces were loaded in two fixtures, one at each end of the table, taking eight pieces each. Two milling cutters were mounted on the arbor, one cutting right-hand and the other left-hand. The fixtures were staggered on the table, and arrangements made to reverse the direction of spindle rotation by double countershaft. Thus parts were loaded in the fixture at one end whilst the other fixture was

in operation. The average production per machine was 40 per hour, and three operators were used on the three machines.

On the production requirements increasing to 4,000 a day, new methods had to be considered, and the best proposal, other than broaching, was a high production milling machine arranged for almost continuous production, with a duplex fixture to permit of loading whilst cutting, each station accommodating six pieces in different positions, so that at each stroke two finished pieces would be produced. The production guaranteed was 150 per hour. Comparison table is as follows :—

PLUNGER PIN—PRODUCTION REQUIREMENTS 4,000 PER DAY.

	Broaching.	*Alternative.*	*Approx. saving.*
Capital cost	One mach., broach bar, fixture. £1,110.	Three machines, pumps, bases, arbors, fix. £2,742.	59%
Tool cost ...	£53 for 400,000 .03d.	£14 for 3,000, est. 1.12d.	98%
Labour cost	650 per hour at 1s. 6d. .027d.	150 per hour per machine at 1s. 6d. .12d.	80%

This installation has been running for approximately ten months. At the time of this installation, two sets of broach inserts were included, which have been ground several times, but are still in use. During this period they have produced approximately 800,000 components.

The milling layout for the cast iron water pump body included the use of a high production machine with two stations, one being loaded whilst the other was milling, making the production almost continuous. The comparison is :—

CAST IRON WATER PUMP BODY.

	Broaching.	*Alternative.*	*Approx. saving.*
Capital cost	One mach., broach bar, fixture. £1,410.	Two machines, fixtures. £1,646.	15%
Tool cost ...	£75 for 120,000 .15d.	£30 for 30,000 .24d.	40
Labour cost	100 per hour at 1s. 6d. .18d.	33 per hour per machine at 1s. 6d. .54d.	66%

This is a comparatively new installation, and the latest figures are not available but, at the time of compiling this paper, the production and results were as given.

The fourth example—the connecting rod—is a component which has had, I should say, as much attention devoted to the question of the best means of machining it as any other component in a motor car, so that the comparison here will be of particular interest, representing as it does the latest high productive layout in milling compared with the relatively new method of surface broaching. The comparison is as follows:—

CONNECTING ROD—PRODUCTION REQUIREMENTS 2,500 PER FORTY-HOUR WEEK.

OPERATION I.

	Broaching.	*Alternative.*	*Approx. saving.*
Capital cost	One mach., broach bar, fixture. £590.	One mach., fixture £1,430.	59%
Tool cost ...	£50 for 50,000. .24d.	£20 for 10,000 (est.). .48d.	50%
Labour cost	130 per hour at 1s. 6d. .14d.	85 per hour at 1s. 6d. .21d.	33%

OPERATION III.

Capital cost	One mach., broach bar, fixture. £570.	One mach., fixture. £904.	37%
Tool cost ...	£50 for 50,000. .24d.	£19 for 5,000 est. .91d.	73%
Labour cost	80 per hour at 1s. 6d. .225d.	80 per hour at 1s. 6d. .225d.	—

OPERATION IV.

Capital cost	One mach., broach bar, fixture. £465.	One machine, fixture. £560.	17%
Tool cost ...	£26 for 120,000. .052d.	£2 5s. for 5,000 (est.). .108d.	50%
Labour cost	320 per hour at 1s. 6d. .05d.	57 per hour at 1s. 6d. .31d.	83%

Although the broaches for surface broaching operations I and III have been ground weekly, and those for operation IV every three weeks, it does not appear to have had any appreciable effect upon their life.

Discussion—Eastern Counties Section.

MR. RACKHAM : I am afraid this is a subject I and many others know very little about, but it has been most interesting. In listening closely I could not quite see the form of broach used in splitting the gap through the big end of the connecting rod. In broaching very thin metal, say $\frac{1}{8}$ in. thick would the lecturer make any special form of broach ?

MR. WEATHERLEY : I am afraid the slide showing the splitting operation was not very clear. However, the broaching tools for this operation comprised two case hardened mild steel broach bars of flat section, one on the left hand side of the fixture and one on the right-hand side, each having two sets of high-speed steel inserts. The broaching tool on the left-hand side splits the cap half way through, and that on the right-hand side completes the splitting. The inserts being of thin section, dual provision has to be made to guide both the broach bar and the inserts.

With regard to the broaching of components with walls, say, $\frac{1}{8}$ in. thick, most of the troubles when broaching these fragile components are due to taking too fine a cut, as this tends to cause a wedging action on the tool, and it will help considerably to overcome this trouble if the amount of cut per tooth is increased.

The external broaching of gear wheels is possible, though not to the degree of accuracy required in the modern motor car. If, however, there is a subsequent grinding operation after hardening, it could be an economical proposition, particularly where large quantities are concerned, to produce gear wheels by surface broaching. As an example, a gear wheel approximately 6 in. diameter could be broached in five strokes, the production time being made up of five cutting strokes occupying, say, twelve seconds per stroke ; return of ram and indexing five times at, say, six seconds per stroke, making a total of ninety seconds each cycle, and, it might be possible that two or three could be broached at one time, so that the production time per gear would be thirty seconds, plus loading and unloading time.

MR. WEBSTER : Would it be possible to broach a hexagon nut, in gunmetal, with a flange at one end, and how would it compare with milling ?

MR. WEATHERLEY : The broaching of a hexagon nut would compare in favour of broaching against milling by approximately two to one. For example, each pair of faces of a 1 in. Whitworth hexagon nut, removing $\frac{1}{32}$ in. of metal per face, in gunmetal, could be finished in 18 in. of cutting stroke, at, say, 20 ft. per minute. Provision would have to be made to keep the flange to a reasonable

limit from the locating face, and, if a set-up was made for a gang of three, one piece would be finished every cutting cycle.

MR. COPPING : I was interested in the bolt facings of the end of the connecting rods. Where you are producing lots of say 200 drop forged connecting rods, and you have five sizes varying from 4½ in. to 12 in. would it be possible to design a broaching bar with the necessary adjustments to allow for the broaching of a group of rods of that type ? In broaching the face of the connecting rods, take for example a rod where the centres have to be within plus or minus .002 in. it may seem simple to bore top and bottom ends correctly, and when checking the operations we have troubles of .004 in. from our fixtures. Would it be possible to broach the face of the rod after splitting and also skim the bore of the gap to restore the correct face.

MR. WEATHERLEY : It is possible that a range of connecting rods such as you suggest, with centres of 4½ in. to 12 in., could be broached on the bolt facings by using a broach bar with suitable location slots to coincide with the varying centres, and one set of broach inserts. The change over from one size to another need occupy no more time than would be the case in milling. Broaching the faces of connecting rods after splitting requires a very simple set-up, and would enable you to maintain centres of ±.0005 in. The set-up for broaching the half bore and face of connecting rods would need to be different for each size. Limits of plus or minus .0005 in. could be obtained.

MR. HOY : I have been very interested in this lecture which has opened my mind very extensively to the possibilities of broaching, and gives great scope for thought. I was rather inclined to disagree with the lecturer on the question of lay out. I see its possibilities in mass production, but a broaching machine would be a costly layout unless you had large quantities.

MR. WEATHERLEY : It is not always necessary to have large quantities to justify surface broaching. There are many components inside the average engineering shop which are very similar in character, and if a set-up is made to cover a range, so that all that is necessary is changing of work holding fixtures, the advantages that surface broaching offers can justify its adoption.

MR. BRAZIER : There was one point which arose in my mind in the broaching of stampings in the black, how to get over distortion if you re-broach to get accuracy. You have given us a very large vision for the future. When people start to standardise their machines I should say their would be a great demand for tools of this kind owing to the reduced times which are colossal. Four hundred or more per hour when you only get forty on a milling machine is going

to revolutionise business. You have mentioned a number of articles which can be broached because of flat surfaces. Have you tried to broach cylinders in cast iron? I do not know if the walls of a cylinder are strong enough to stand a broach. With regard to the broaching of rack teeth, do you do anything with that? The one item which really does interest me is what the production engineer must look to in the future. To my mind it is most interesting, and I should think if we start looking into things, we shall find many things we can broach.

MR. WEATHERLEY: There should be no distortion in the broaching of stampings; but, if the component is of such a nature that the removal of metal releases internal stresses, then of course it is necessary, as in other forms of machining, to re-clamp and to have a finishing operation. There is no doubt that greater accuracy is obtainable from broaching than milling. With regard to the broaching of cylinders in cast iron, this practice was discontinued many years ago. I think the requirements of cylinders to-day are such that broaching is not an economical proposition. With respect to the broaching of rack teeth, this is now quite common practice and presents no difficulties. The production is such that a rack 36 in. long, 1 in. face, 12 pitch, can be broached at the rate of 30 per hour, with a suitable set-up.

MACHINE TOOL PROBLEMS.

By James A. Mansell, Grad.I.P.E.

(NOTE.—*This essay was adjudged to be the best of those presented by the candidates at the* 1937 *Graduateship Examination.*)

MANUFACTURING to-day is, to a large extent, a battle of equipment. Machine tools form a large part of modern equipment. Each machine tool bought is an investment. There are many factors influencing its production performance or service earnings. The works manager or production engineer who can assess these factors, and overcome the problems arising from the selection, maintenance and use of machine tools, gives useful service to his organisation.

These problems are many and varied. No two concerns are alike, and each firm has its own production policy to consider in relation to the machine tools used. Let us concern ourselves with the machine tool problems applicable to the majority of plants or the general problems. These may be summarised as follows: When are new machine tools required for replacement purposes? Are new machine tools essential when the product is changed? What is the best type of machine tool for the job? Where, and how, can the machine tool be installed to its best advantage? What factors are essential to ensure maximum performance from the machine tool?

In deciding when replacements are necessary it is obvious that the production engineer requires a thorough knowledge of his entire plant.

The life of a machine tool is limited by obsolescence, or its mechanical condition. It may vary from one to three years in the case of the special purpose machine, or ten to fifteen years with the standard machine, depending upon type, nature of service, and operating conditions. In deciding this question of replacements the production engineer should have information regarding the age, present condition, and maintenance costs of each machine tool. A machine tool may be obsolete if money is saved by replacing it.

When production is being scheduled for new articles, the first question is: Can the components be produced by the existing machine tools? If so, will this production be economical? Com-

parison should be made between the production times on existing machines, and the estimated production times on new machines. Will the saving in production times make the purchase of new machine tools economical ?

The selection of the machine tool is governed in the first place by manufacturing policy. The range of products, and the scale of their manufacture are the deciding points between machine tools of standard types, and special purpose machines. Knowing the type of products, and the estimated production required, the problems to be decided by the executive responsible are whether he can obtain satisfactory production with standard machine tools, will he have to modify standard machine tools to get this production, or will it be necessary to lay down machines specially designed for dealing with the product. Where the standard machine is modified by the addition of new parts, special fixtures, or alteration in the speed and feed mechanism, the cost of the alteration, plus the cost of its maintenance, have to be added to the initial cost of the machine.

The initial cost of the special purpose machine is usually higher than that of the standard machine. It gives higher output and may cut production times by 50%. This type of machine being designed to deal with a particular product is often scrapped when the product is changed. This means that the cost of the special machine tool has to be recoverd on the one job.

The standard machine may be adopted to suit various forms of work, and this versatility makes for longer machine life. The initial cost of the standard machine tool, plus the cost of its adaption and maintenance, its longer useful life, and slower depreciation, have to be carefully compared as against the special type of machine, its higher initial cost, and maintenance, its shorter useful life, and quick depreciation, and its saving in production time.

When the plant is engaged on continuous mass production of standardised articles the use of specially designed machines is warranted. The larger the production, the greater the scope for research into the best methods of speeding up that production, by improving the design of the machine tools employed. Many of the large organizations engaged on mass production, design and build some of their own special purpose machines around their products. For the production of articles in variety and small quantities, it is obvious that standard machine tools are essential. Quick adaption and setting up are necessary if machining costs are to be kept as low as possible.

It is important to consider the most efficient machine for the major portion of the production, too much attention should not be paid to occasional production. The greatest saving is made on

the largest amount of work, if the small quantity jobs are allowed to influence the decision when buying new machine tools, this will result in a decrease of the general efficiency.

Another problem occupying the attention of the production engineer periodically, is that of modernising his equipment. To what extent is the reconditioning of machine tools economical? The question of overhauling machine tools needs careful investigation. Only machine tools that are failing by reason of wear and tear need be considered. It is waste of money attempting to recondition machines that are becoming obsolete. This problem of reconditioning assumes more importance at the present time than it did previously. The present all round increase in the demand for machine tools of all types, has led to the machine builders quoting delivery dates six, and even twelve months ahead. Firms having the capital available cannot always obtain the machines they require. A plant having to make an immediate change in production routine and unable to get new machine tools quickly, must of necessity recondition existing equipment to meet the change of product.

Certain machine tools, by an overhaul and the addition of new parts can be made reasonably efficient, and their useful life prolonged. For example, a capstan lathe may be restored to efficiency by fitting a new spindle, a new screw on the crosslide, and correcting wear on the raised Vee slides by scraping. The bottom face of the turret may need scraping true, as it sometimes wears slightly concave. Similarly a turret lathe may be reconditioned by adding a new spindle and feed screw and correcting wear on the raised Vee slides. These two machines may be reconditioned for a fraction of the cost of a new machine.

In choosing machine tools for reconditioning the production engineer knows that a machine needing constant repairs is useless for this purpose. Such a machine would increase maintenance costs, and develop into an increasing liability instead of a decreasing asset.

The location of a machine tool will influence its performance. It is usual practice to locate heavy machine tools, planers, boring mills, and the like, on the ground floor because of their weight. This brings the larger machines nearer to the supply of the metal to be worked. Certain machine tools are likely to cause vibration, the problem of absorbing this vibration is sometimes solved by mounting the machines on pads of hard rubber. Bolts are taken from the machine foot, through the rubber, into the concrete foundation, the bolts can be adjusted to prevent too much "give" in the rubber. Machine tools are frequently idle while components are transported to, and from them.

By grouping his machine tools to facilitate the handling of the work, the production engineer can cut down idle machine time. Where the production is such that the components flow from machine to machine until completed, and if the intention is to replace an existing machine with a new one, the engineer concerned is faced with another problem.

The production speed of the whole line of machines will have a bearing on his choice of the new machine. No useful purpose would be served by the purchase of a super machine, it would only be operating to the capacity of the line, and its higher output capabilities wasted. Can the whole line of machines be speeded up to suit the new replacements, or can he afford to run the new machine at its lessened capacity until he can replace the whole section with new machines? After installing and bedding down the new machine tool, if acceptance tests are made, the production engineer obtains useful information on the capabilities of the machine.

Having purchased and installed his machine tool, the production engineer is concerned with the factors that control its operating efficiency. The modern trend is towards motorising machine tools whenever possible. This helps the engineer. If a machine tool is a self-contained unit, the problems of shafting and countershafting are eliminated. The built-in motor driving through suitable gears, saves time by allowing instantaneous speed changes to be made. This type of machine lends itself to quicker installation, and removal, than the belt driven machine that has to be coupled to shafting.

With machine tools driven by belting, either direct from a motor, or from shafting, it is important for the engineer to know if the full amount of available power is being transmitted to the machine. Machine production is based upon speed of operation, a drive that slips does not maintain the theoretical ratio from scource of power. It decreases the operating efficiency of the machine. The rated capacities of the machine should be frequently checked with the actual production. If the leather drive tends to slip, resulting in loss of power, to what extent will chain or Vee rope drives correct this tendency?

Where the motor is built into the machine, but direct drive is not possible, a chain drive is often found best. The motor in most cases can be moved slightly to adjust the chain when necessary. On machine tools taking intermittent cuts, it is particularly important that the drive gives continuous uninterrupted service.

If the production engineer is to get the best results from his machine tool equipment he has to pay attention to the question of lighting. Efficient lighting of the machine tool helps to increase the output from it, and lessens the possibility of accidents to the

operator and setter. In addition to the general shop lighting each machine tool requires at least one adjustable lamp. Plenty of light on the loading stations and tooling equipment will reduce the amount of faulty work. The builders of the machine tool know its capabilities and the points where failure might occur. The life of the machine tool may be lengthened, and its maintenance cost kept low, by following its manufacturer's instructions regarding cleaning and lubricating.